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METHODS OF MEASUREMENT FOR HOT CATHODE GAS FILLED TUBES

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MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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December 1982

Indian Standard

METHODS OF MEASUREMENT FOR HOT CATHODE GAS-FILLED TUBES

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(*Continued on page* 2)

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Indian Standard

METHODS OF MEASUREMENT FOR HOT CATHODE GAS-FILLED TUBES

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 20 October 1981, after the draft finalized by the Electron Tubes Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

0.2 This standard deals with the methods of measurements of the characteristics of hot cathode gas filled electron tubes.

0.3 In preparing this standard, assistance has been derived from IEC Publication 151-17 (1969) 'Measurements of the electrical properties of electronic tubes: Part 17 Methods of measurement of gas-filled tubes and valves' issued by the International Electrotechnical Commission.

0.4 In reporting the result of a test made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960*.

1. SCOPE

1.1 This standard covers the methods of measurements of the characteristics of the following types of hot cathode gas-filled electron tubes:

a) Hot cathode tubes,
b) Gas-filled rectifier tubes, and
c) Thyratrons, except for those used for pulse modulation.

2. TERMINOLOGY

2.0 For the purpose of this standard, the definitions given in IS : 1885 (Part IV/Sec 1)-1973†, in addition to the following shall apply.

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*Rules for rounding off numerical values (*revised*).

†Electrotechnical vocabulary : Part IV Electron tubes, Section 1 Common terms (*first revision*).

2.1 Gas-filled Rectifier Tube — A gas-filled tube whose function is to rectify an alternating current.

2.2 Thyratron — A hot cathode gas-filled tube in which one or more electrodes initiate, but do not control the anode current.

2.3 Electrodes and Gaps

2.3.1 *Main Gap* — The conduction path which carries the load current.

2.4 Critical Grid Voltage — The instantaneous value of the grid voltage in a thyratron at which the load current starts to flow across the main gap for a specified anode voltage and under specified conditions.

2.5 Critical Anode Voltage — The instantaneous value of the anode voltage in a thyratron at which the load current starts to flow across the main gap for a specified grid voltage and under specified conditions.

2.6 Control Characteristic — A relation, usually shown by a graph, between critical grid voltage and anode voltage.

2.7 Maintaining Voltage — The difference of potential between the cathode and a stated electrode of a gas-filled tube when that electrode is carrying current.

2.8 Repeatability of Difference of Potential — The ability of a gas-filled tube to attain the same anode maintaining voltage at a stated time after the beginning of any conducting period.

NOTE — The lack of repeatability is expressed by the change in this voltage from one conducting period to any other, the operating conditions remaining unchanged.

2.9 Voltage Jump — An abrupt change in the tube voltage drop of a thyratron during operation.

NOTE — This may occur either during life under constant operating conditions, or as the current or temperature is varied over the operating range.

2.10 Critical Grid Current — The value of grid current corresponding to the critical grid voltage at the instant when the discharge has just been established.

2.11 Ionization Time — The time interval between the initiation and the establishment of a discharge in a gas-filled tube, for example, the time interval from the application of the grid voltage to the instant at which the tube voltage drop attains a stated value under specified operating conditions.

2.12 Recovery Time — The time required after interruption of anode current for the grid to regain control under specified operating conditions.

2.13 Condensed Mercury Temperature — The temperature measured on the outside of the tube envelope in the region where the mercury is condensing (in tubes with glass envelopes) or at a specified point (in tubes with metal envelopes).

3. PRECAUTIONS FOR MEASUREMENT

3.1 The characteristics of gas-filled tubes differ substantially from those of vacuum tubes. Because the tube voltage drop is nealry independent of the magnitude of current conducted and the grid in general has no control after the discharge has started, the current through the tube is determined principally by the applied voltage and the circuit parameters. Sufficient impedance shall always be used in series with the anode and the grid to limit the anode and grid currents, following ignition, to values low enough to prevent damage to the tube.

3.2 The pressure of the vapour in mercury vapour tubes affects the electrical characteristics and is a rapidly varying function of the condensed mercury temperature. In measuring mercury vapour tubes care shall therefore be taken to control condensed mercury temperature in order to obtain reproducible results. In general, with increase of temperature, the tube voltage drop and peak forward voltage will decrease, the peak inverse voltage that the tube will withstand will decrease, the critical grid voltage will become more negative and the recovery time will become longer.

3.2.1 In general, the time required to attain the desired condensed mercury temperature is longer than the cathode heating time.

3.3 When measuring the maximum peak inverse voltage or the control characteristics, precautions must be taken to ensure that no condensed mercury exists in the upper parts of the tube. This is generally achieved by a preheating process in which only cathode heating power is applied to the tube. The tube must be maintained in an upright position, away from air currents, in order to prevent mercury from recondensing in the upper part of the envelope. Where forced air cooling is used, it should be so arranged that no temperature differential is created resulting in condensation of mercury in the upper part of the envelope.

4. METHODS OF MEASUREMENT

4.1 Filament or Heater Electrical Characteristics

4.1.1 Readings of heater current and voltage are taken with voltage applied only to the filament or heater terminals. The current should be measured when it has reached equilibrium.

PRECAUTION — The resistance of a cold filament or heater is much smaller than its resistance under normal operating conditions. If the filament of a tube of high power is connected directly to the heating source, excessive filament current may flow and cause damage to the tube or to the measurement equipment. Therefore, it may be necessary to limit the filament current to some specified starting value.

For tubes with high filament current, it may be necessary to correct for voltage drop in the socket when the voltage is measured at the socket terminals.

4.2 Control Characteristics

4.2.0 Data for plotting the control characteristics are obtained as follows.

4.2.1 *Critical Grid Voltage*

4.2.1.1 With voltage applied to the filament or heater, and with sufficient direct voltage applied to the control grid to prevent conduction, alternating voltage is applied to the anode through a resistance which will limit the current during conduction to a suitable value (*see* Fig. 1).

4.2.1.2 The control grid voltage is gradually made more positive (or less negative) until anode current flows as a result of breakdown (the occurrence of an arc) between the anode and the cathode of the tube and the critical grid voltage is noted just before the discharge. If the critical grid voltage is positive, appreciable grid current may flow before breakdown. The grid voltage must then be measured at the grid terminal.

4.2.1.3 The condensed mercury temperature of mercury vapour tubes should be held to the desired value, which should be recorded with the results. This value is dependent upon operating conditions and the tube structure, but it is in general between 20°C and 50°C. For tubes having shield grids, the shield grid potential is an additional parameter, and should be held at a specified value, usually zero.

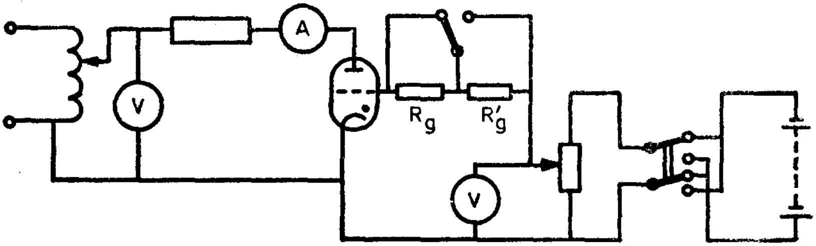


FIG. 1 CIRCUIT ARRANGEMENT FOR MEASURING GRID CURRENT AND VOLTAGE

PRECAUTION — It may be necessary to use a capacitor of small value between each grid and the cathode to prevent possible anode voltage surges from affecting the grid voltage. A capacitor can affect the result if the measurement is made using a grid resistor of large value. This is because the capacitor integrates the grid current which flows during different parts of the cycle.

The grid resistor shall be sufficiently high to avoid overloading the grid when the tube is conducting and sufficiently low to have negligible affect on the measured result.

For directly heated tubes it is normally necessary to specify that the cathode return be made either to the centre tap of the filament transformer or to the centre tap of the filament if present.

However, in the case of tubes having a filament terminal which is internally connected to a filament shield and which is specified by the manufacturer to be used as a cathode terminal the voltage reference point must be the terminal quoted by the manufacturer.

If the tube is directly heated, the relative phasing of the filament and anode voltages should be prescribed.

4.2.2 *Critical Anode Voltage*

4.2.2.1 With voltage applied to the filament or heater, the grid or grids, if present, are held at desired voltages and the alternating anode voltage is increased until anode current flows as the result of breakdown (the occurrence of an arc) between the anode and cathode of the tube. The peak value of the anode voltage at this point is the critical anode voltage. Sufficient resistance must be inserted into the anode circuit to limit the current during conduction to a suitable value.

PRECAUTION — For directly heated tubes it is normally necessary to specify that the cathode return be made either to the centre tap of the filament transformer or to the centre tap of the filament if present.

However, in the case of tubes having a filament terminal which is internally connected to a filament shield and which is specified by the manufacturer to be used as a cathode terminal, the voltage reference point must be the terminal quoted by the manufacturer.

If the tube is directly heated, the relative phasing of the filament and anode voltages should be prescribed.

4.3 Emission

4.3.1 For a tube of given design, the voltage drop is primarily a function of emission. Lower voltage drop is an indication of higher emission.

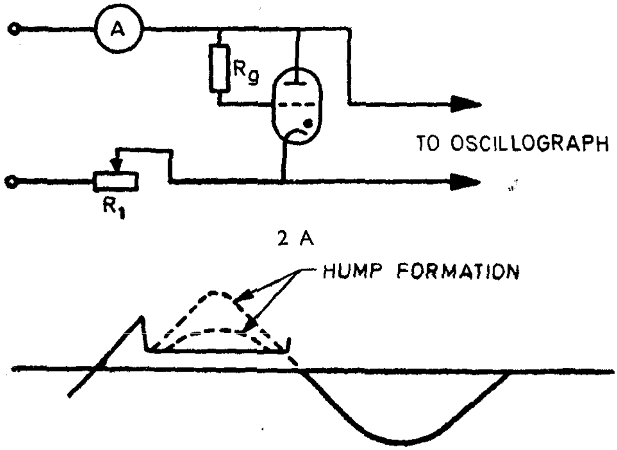
4.3.1.1 The electron-emission characteristic of a gas-filled tube is commonly determined by measurement of the voltage drop at an anode current sufficiently high to indicate cathode capability. This is sometimes done under conditions of continuous-current conduction.

4.3.1.2 An intermittent-conduction method is more accurate because of the reduction of cathode heating or cooling by arc current. Formation of a cathode spot, as indicated by a discontinuous reduction in the arc drop, indicates faulty cathode operation.

4.3.2 *Direct and Alternating Voltage Methods*

4.3.2.1 With the desired voltage applied to the filament or heater, with an anode supply voltage sufficient to cause firing, and with the cathode current limited to the desired value by a series resistor, the voltage drop is measured by a voltmeter if direct voltage is used, and by an oscillograph or other suitable means if alternating voltage is used. In the latter case, the voltage is read at the instant the current is at its peak value.

4.3.2.2 The tube to be measured shall be inserted into the low voltage circuit of an alternating voltage source (*see* Fig. 2A). The grid shall be connected to the anode through a given resistance R_g. By varying the load resistance R_1, an effective value of the anode current can be read at the moment at which a hump on the anode voltage curve is observed on the oscillograph screen (*see* Fig. 2B). The peak value of the anode current which is approximately equal to the cathode emission current is calculated from the effective value of the anode current.



2 A

2 B

FIG. 2 DETERMINATION OF THE CATHODE EMISSION CURRENT BY MEANS OF AN OSCILLOGRAPH DISPLAYING THE CURVE OF THE TUBE VOLTAGE DROP

4.3.3 *Intermittent Voltage Method*

4.3.3.1 With the desired voltage applied to the filament or heater, with the cathode current limited to a desired value by the circuit, and with the anode voltage to be applied intermittently at a duty factor such that appreciable heating or cooling of the cathode does not occur, the tube voltage drop is measured by an oscillograph or other suitable means at the instant when the current is at its peak value. The period of conduction shall be of sufficient duration to ensure that the tube is sufficiently ionized to make the measured voltage drop independent of the conduction period.

PRECAUTION — In both these methods any grids having separate terminals should be connected to the anode either directly or through a current limiting resistor. The value of resistance shall be specified since the tube voltage drop is affected by the current distribution between the grid and the anode.

Since the voltage drop in mercury vapour tubes varies with vapour pressure, the permissible range of condensed mercury temperature should be controlled within narrow limits.

4.4 Grid Current

4.4.1 The critical grid current of a thyratron is a function of the anode voltage and includes positive ion, electrons and leakage currents. The interelectrode capacitance charging currents may also be important.

4.4.1.1 These grid currents are usually of low value. They are generally measured by reading the voltage drop across a resistor in series with the grid.

4.4.2 *Critical Grid Voltage Method* (*for Tubes having Negative Control Characteristics*)

4.4.2.1 The critical grid voltage method for determining grid current is usually employed with the tube heated to operating temperature by conduction of rated average anode current. With the desired value of alternating anode voltage and with the grid supply voltage adjusted to assure substantially full half-wave conduction, the impedance of the anode circuit is adjusted so that the specified anode current is established. With a resistance R_g in series with the grid, as shown in the circuit of Fig. 1, the grid supply voltage is then made more negative until conduction ceases.

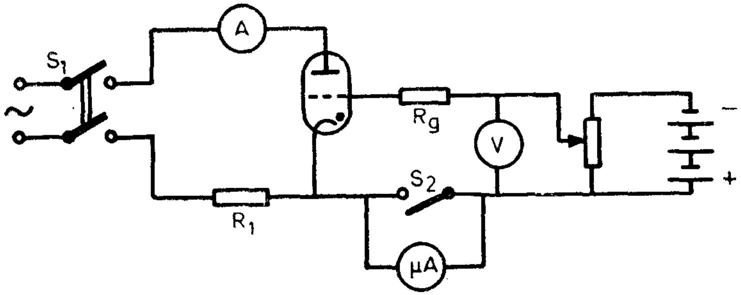
This voltage is denoted by V_1. The measurement is then repeated with a different resistance R_g, which should be sufficiently low so that there is a negligible voltage drop across it due to preconduction grid currents and sufficiently large to avoid variations in grid supply voltage resulting from the grid current during conduction. The second measured value is denoted by V_2. Since the critical grid voltage can be assumed to have the same values in both measurements, the grid current flowing just before conduction is:

$$i_g = \frac{V_1 - V_2}{R_g - R'_g}$$

4.4.2.2 Normally R'_g is much less than R_g and can be neglected. The frequency should be low enough for the effect of the tube and circuit capacitances to be neglected. The primary electron emission from the grid is a function of the grid temperature. In order that the full value of total grid current can be measured, the grid must be heated by operating the tube at the desired values of anode current for an adequate time immediately before the measurements are made. In this measurement, the shield grid, if any, is connected to the cathode. Other grid current measurements may be made with direct voltage on the shield grid.

PRECAUTION — This method may be inaccurate if the positive ion current to the grid resulting from the preconduction current in the thyratron is comparable in magnitude to the other grid current components, and if the value of R_g is too great.

4.4.3 *Grid Thermionic Emission Current* — The tube to be measured is connected as shown in the circuit of Fig. 3. Before measurements are made, the tube shall carry the nominal anode current for the time required for all its parts to be heated and to reach a stable temperature.



NOTE — The switches S_1 and S_2 are ganged, so that they open simultaneously.

FIG. 3 CIRCUIT ARRANGEMENT FOR MEASURING THE GRID THERMIONIC EMISSION CURRENT

A negative grid voltage of a value sufficient to extinguish the discharge is then applied, the anode circuit is disconnected and simultaneously the micro-ammeter is connected into the grid circuits.

PRECAUTION — The mercury vapour tubes should be measured at the maximum permissible ambient temperature.

4.5 Surge Current

4.5.1 The ability of a tube to withstand a forward surge current without excessive damage is checked in a circuit in which the tube is connected in series with a high current device such as an ignitron, as shown in Fig. 4.

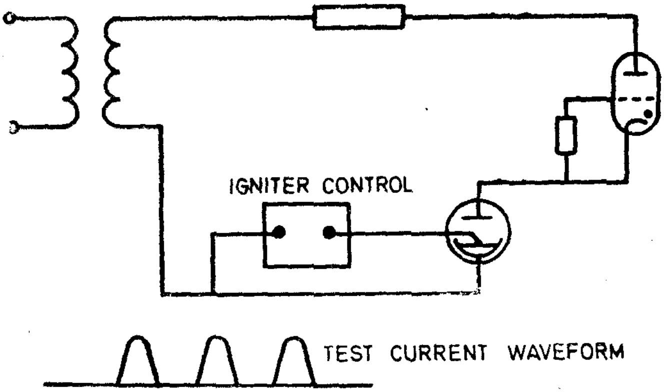


FIG. 4 CIRCUIT ARRANGEMENT FOR SURGE CURRENT MEASUREMENTS

4.5.2 By control of the ignitron, the desired peak value of half-wave current can be passed through the tube for a definite time.

4.6 Operation Measurement

4.6.1 Gas-filled tubes may be subjected to an operation measurement by operating them in conventional rectifier circuits. This is intended for observing any visual flash over inside when the tube is subjected for a specified peak inverse voltage and time. Fig. 5 shows a typical full wave, single-phase circuit. Fig. 6 shows a typical three-phase zig-zag circuit as connected for thyratrons. When measuring diodes, the grid circuits are eliminated. The tube is operated at a definite temperature for a definite time to observe the frequency of arc-back and whether grid control is lost. The severity of the measurement condition depends upon a number of factors such as those illustrated in Fig. 7.

4.6.2 The following also include some other important factors:

a) Peak anode current,
b) Peak inverse anode voltage,
c) Current at the beginning of commutation,
d) Inverse voltage immediately after commutation,
e) Commutating time, and
f) Arc-back current (being a short circuit current not shown in the waveform).

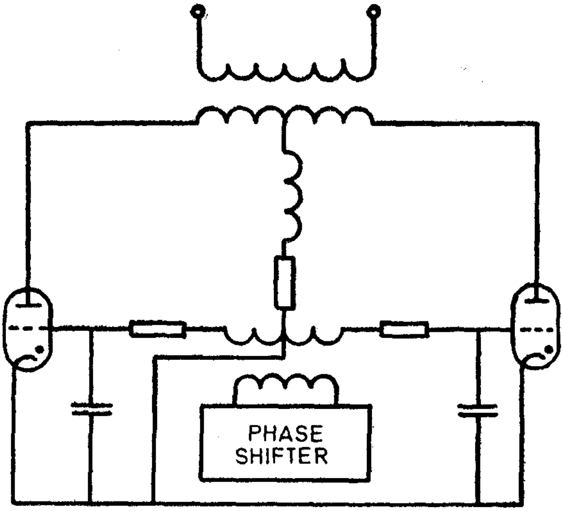


Fig. 5 Circuit Arrangement for Single-Phase Rectifier Operation Measurement

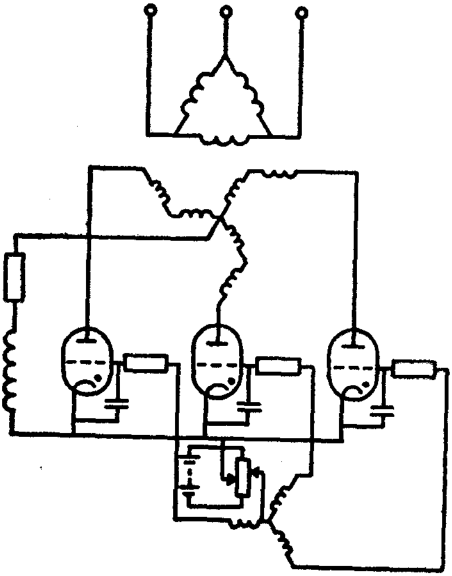


Fig. 6 Circuit Arrangement for Three-Phase Rectifier Operation Measurement

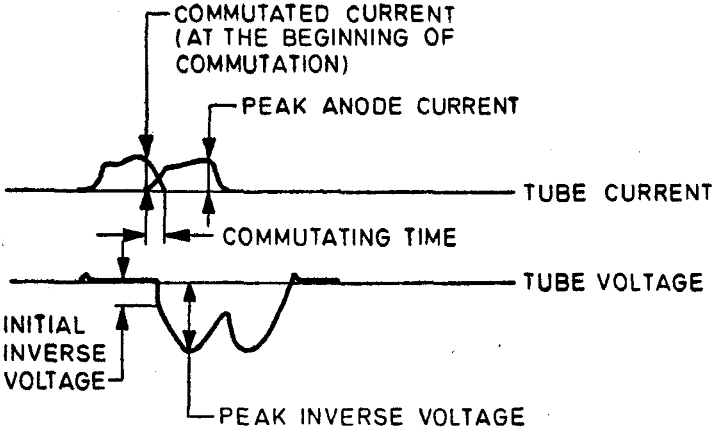


FIG. 7 TYPICAL THREE-PHASE RECTIFIER WAVEFORMS

4.6.3 The magnitude of these factors depends upon the following circuit parameters:

a) Number of phases of the rectifier,
b) Type of filtering circuit,
c) Transformer impedance,
d) Type of load circuit (the power may be absorbed either by a resistor or by a reverse emf load. Examples of the latter are a battery, a capacitor, or a motor, which can increase the arc-back current),
e) Firing angle in grid controlled tubes, and
f) The impedance of the arc-back circuit.

4.6.4 The correlation of measurement results may be difficult unless the measurements are made under conditions that are identical with respect to the foregoing parameters. For convenience, this measurement is often made with a full wave, single-phase rectifier operating into a resistive load, such as a water resistor. The influence of the factors (c), (d) and (e) in **4.6.2** is then minimized. In order to make the measurement comparable in severity with a polyphase measurement, it is usually necessary to increase the measurement, voltage.

4.6.5 *'Cheater Circuit' Measurement*

4.6.5.1 It is possible to construct measurement circuits, called 'cheater circuits', which simulate the current and voltage waveforms of the circuit described in **4.6**. These circuits usually consist of high-current, low-voltage sources of power to supply the forward current through the tube under measurement, and low-current high-voltage sources to supply inverse voltage after the end of the conduction period. Synchronous switching methods are used to switch from one source to another at the proper time in the cycle. The object of such circuits is to reduce the energy requirements and the equipment cost. This usually requires that the high-voltage source of power be of relatively small capacity and high impedance. The current through the tube on occurrence of arc-back is therefore relatively small. Under such conditions, it is possible that the rate of occurrence of arc-back may be reduced compared to that which would be obtained from a power source of lower impedance. By the use of sensitive arc-back indicators, the small reverse currents that flow when arc-back occur can be observed. Such a method of measurement requires careful correlation of measurement results with those obtained under actual working conditions. The thermal conditions of the tube are different from those under normal working conditions as the anode bombardment is reduced during the non-conduction period because of the high impedance of the circuit. The switching between sources is done by a rotating commutator or by a suitable thyratron circuit. Fig. 8 shows one form of ‘ cheater circuit ’ in which switching is accomplished by thyratrons.

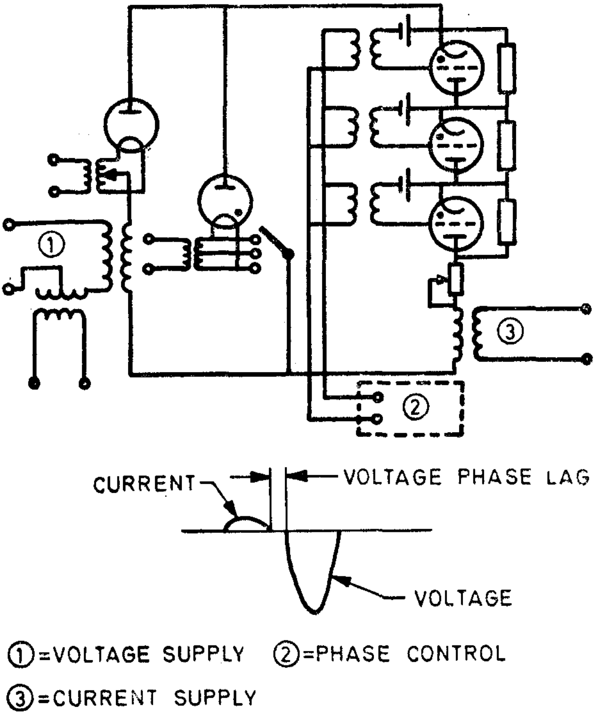


FIG. 8 TYPICAL ‘CHEATER CIRCUIT’ RECTIFIER MEASUREMENT

4.7 Thermal Measurements for Hot Cathode Mercury Tubes

4.7.1 The operating temperature of a hot cathode mercury vapour tube cooled by air convection, depends on the power dissipated in the tube and on the efficiency of the air cooling. The latter depends on the ambient air temperature and on the air flow past the cooling surfaces of the tube. The time required for the temperature of a tube to rise from a low value to its minimum desired operating value depends on the filament power and on the ambient temperature. Tube arc losses are not involved, because the tube should not be allowed to conduct before it is heated to the minimum operating temperature.

4.7.2 The temperature should be measured on the outside of the tube envelope at a point approximately 1 cm above the base.

4.7.3 Baffles or other means should be used to prevent extraneous air currents.

4.7.4 *Condensed Mercury Temperature*

4.7.4.1 The method of measuring the condensed mercury temperature is by means of a thermocouple in close contact with the tube in the region in which the mercury is condensing. The location of the thermocouple is usually immediately above the base of a glass tube or on the radiator of a metal tube. The diameter of the thermocouple wire must be small enough to make the error caused by heat conduction negligible. The measurement can also be made by means of a thermistor thermometer or with a mercury or alcohol thermometer.

4.7.4.2 *Rate of condensed mercury temperature rise* — The condensed mercury temperature of the tube is measured as a function of time, starting at the time the heater circuit is closed. The heater voltage should be held constant, preferably at the lowest desired operating value. The data obtained may be plotted as a curve of temperature rise above ambient temperature *versus* time.

4.7.5 *Equilibrium Condensed Mercury Temperature Rise*

4.7.5.1 With the filament or heater voltage at the highest operating value and with maximum average anode current, the condensed mercury temperature rise at equilibrium is measured for various ambient temperatures. The data obtained may be presented as a curve of condensed mercury temperature *versus* ambient temperature.

4.8 Recovery Time

4.8.0 The recovery time is a function of a number of variables, among the more important of which are the voltage and the impedance of the grid circuit, the anode current prior to extinction of the anode voltage, and (in mercury vapour tubes) the temperature of the envelope.

4.8.1 *Capacitor Discharge Method*

4.8.1.1 *Method* 1 — If a charged capacitor is connected between the anode and the cathode of a conducting gas-filled tube in the proper polarity to make the anode negative with respect to the cathode, the anode current will be interrupted. The current initially flowing through the tube then discharges the capacitor and the anode voltage rises towards the anode supply voltage at a rate dependent upon the parameters of the discharging circuit. At the same time, the anode voltage required for re-ignition rises at a rate dependent upon the rate of disappearance of ions in the inter-electrode region. If the anode voltage at no time exceeds the re-ignition voltage, the anode current remains off until the grid voltage is again raised above the critical value. Figure 9 shows a circuit using this principle to a measure recovery time. The tube under measurement is conducting direct current of the desired value. The capacitor, which is connected in parallel with the load resistor R_1 is charged via R in such polarity that the terminal connected to the tube anode is negative. When the switch is closed the anode voltage V_a becomes negative, and the conduction therefore ceases. The capacitor then discharges through the load resistor R_1. The waveform of the voltage across the tube is also shown in Fig. 9.

In this method, the recovery time, t, is arbitrarily considered to be the time taken by the anode voltage V_a to rise to a value equal to the tube voltage drop, with the capacitance adjusted to the smallest value at which the tube stops conducting for a desired percentage of a number of trials. The recovery time can be calculated from the formula:

$$t = RC\ l_n \frac{2V_s - V_a}{V_s - V_a}$$

where

V_a is the tube voltage drop, and
V_s is the supply voltage.

NOTE — When the tube voltage drop is less than 10 percent of the anode supply voltage, it may, without serious error, be assumed to be zero. The formula for recovery time then simplifies to $t = 0{\cdot}7RC$.

4.8.1.2 *Method* 2 — In the circuit arrangement given in Fig. 10A the capacitor discharge takes place directly in the RC circuit. The required voltage V_g should be applied to the grid of the tube being measured. Then the voltages V_1 and V_2 are applied, the switch S_1 being in position 1. To initiate anode breakdown the anode voltage is applied to the grid for a short time by means of switch S_2.

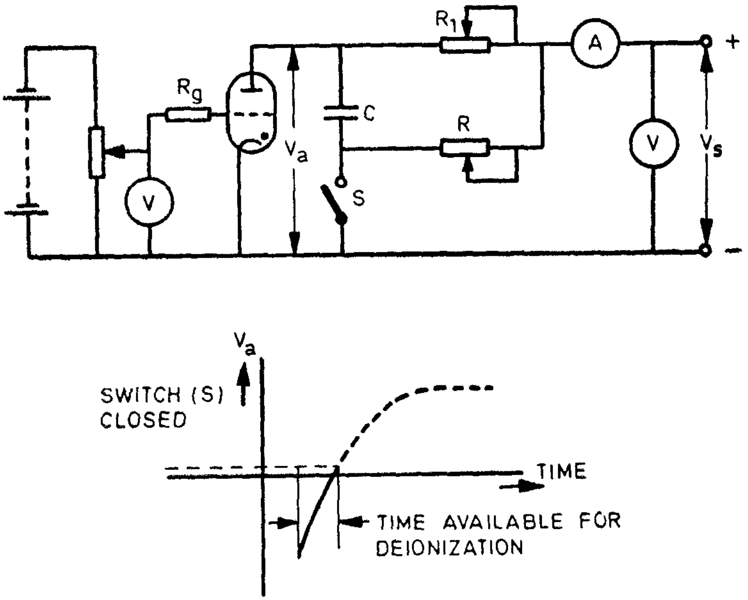


FIG. 9 CIRCUIT ARRANGEMENT FOR MEASURING RECOVERY TIME BY CAPACITOR DISCHARGE METHOD

The current in the load circuit of the tube under measurement should then be adjusted to the desired value. After this, the tube carries the anode current for the time required to reach thermal equilibrium.

When the switch S_1 is returned to position 2, the conduction in the tube ceases and the anode re-ignition voltage of the tube begins to rise. At the same time, a rise of voltage between the anode and cathode will occur. The rate of the anode voltage rise is determined by the time constant of the capacitor discharge (RC). The moment the anode voltage reaches a value equal to the re-ignition voltage anode breakdown again occurs. This value of the re-ignition voltage is determined by means of an oscillograph and several values are measured by varying the capacitance C.

The recovery time, t, can be calculated from the formula:

$$t = RC\, l_n \frac{V_2 - V_a}{V_1 - V_3}$$

where

V_a is the tube voltage drop, and
V_3 is the re-ignition voltage.

The characteristics of the anode re-ignition voltage *versus* time is plotted from the measured values of the re-ignition voltage and the corresponding calculated values of the time obtained both at the fixed grid bias and at the constant load current (*see* Fig. 10B). This method makes it possible to plot the initial part of the characteristic of the recovery time *versus* time.

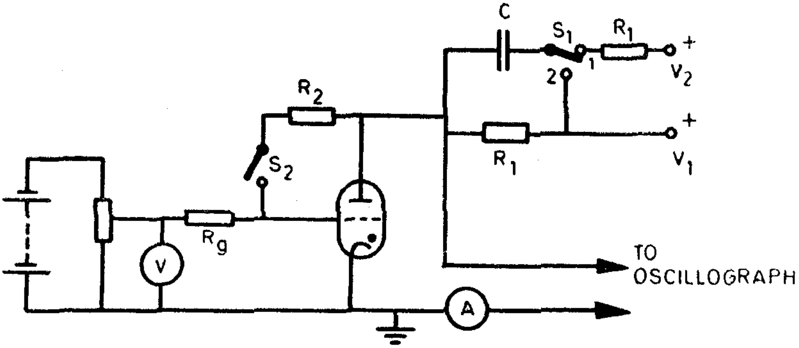


FIG. 10A CIRCUIT ARRANGEMENT FOR DETERMINING THE RECOVERY TIME BY ALTERNATIVE CAPACITOR DISCHARGE METHOD

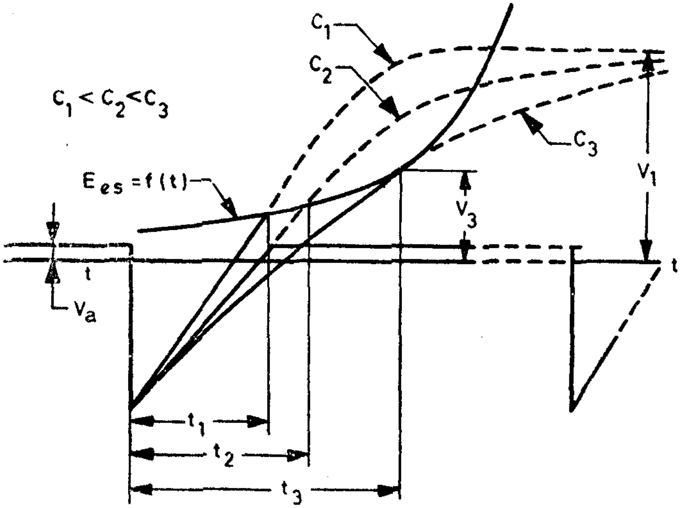


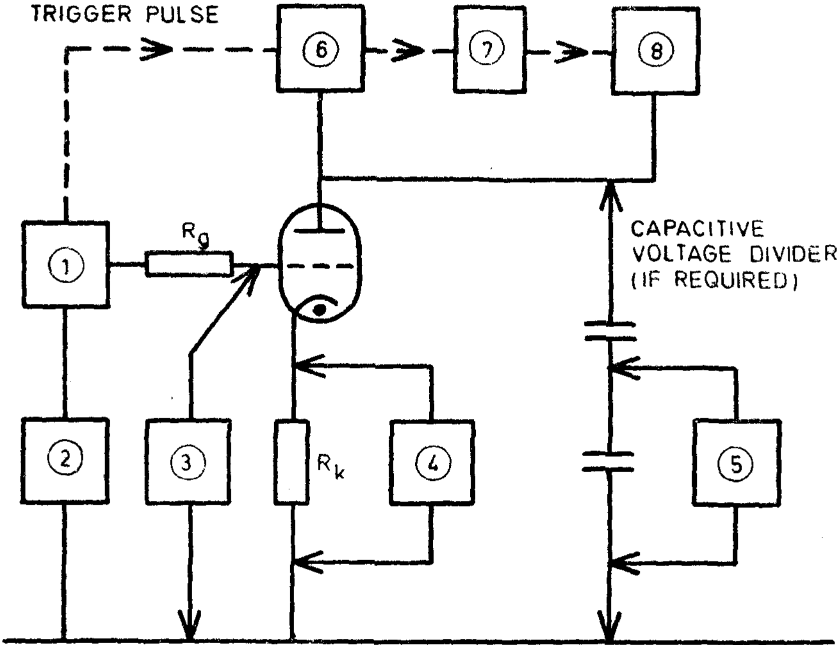
FIG. 10B CURVE ILLUSTRATING THE METHOD OF MEASURING THE RECOVERY TIME ACCORDING TO THE CIRCUIT OF FIG. 10A

4.8.2 *Pulse Method*

4.8.2.1 This method consists of passing a rectangular pulse of current through the tube under measurement and then, at a variable time after the cessation of anode current, applying to the anode a rectangular voltage pulse in the forward direction.

4.8.2.2 It is usually convenient to obtain the anode current pulse and the anode voltage pulse from different pulse generators. The time and amplitude of the pulses are measured using suitable cathode-ray oscilloscopes.

4.8.2.3 This method is repetitive and a 50 Hz, 60 Hz or greater repetition rate gives continuously observable results. A block schematic diagram is shown in Fig. 11 and the waveforms that occur are shown in Fig. 12.



1. Grid pulse generator (low impedance)
2. Grid supply voltage
3. Cathode-ray oscilloscope for grid voltage measurement
4. Cathode-ray oscilloscope to measure I_k
5. Cathode-ray oscilloscope for anode voltage measurement
6. Anode current pulse generator
7. Probe pulse delay
8. Probe pulse generator

FIG. 11 BLOCK SCHEMATIC DIAGRAM FOR PULSE METHOD OF RECOVERY TIME MEASUREMENTS

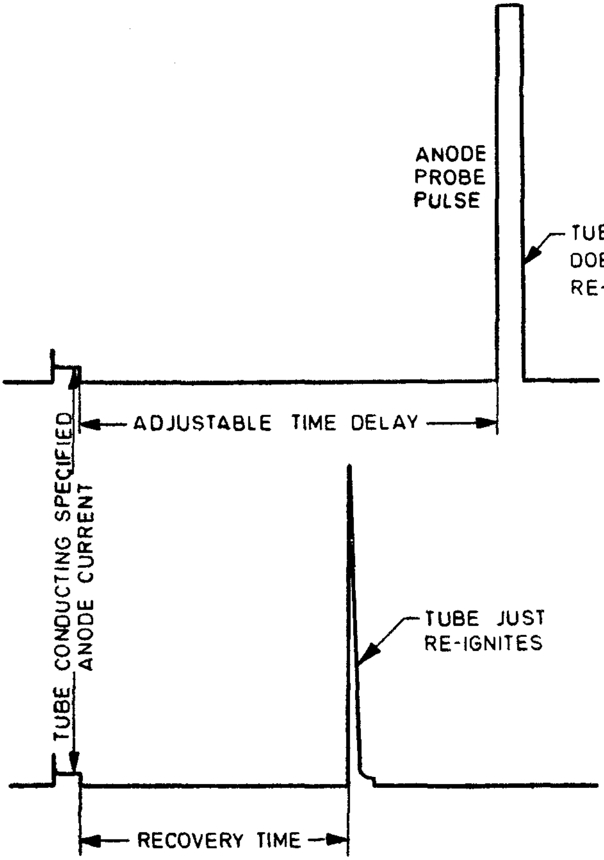


Fig. 12 Diagrams Showing the Anode Waveforms When Measuring Recovery Time by the Probe Pulse Method

4.8.2.4 The current pulse through the tube is adjusted to the required value. This is measured with the oscilloscope input connected across a small current measuring resistor (R_k) in the tube cathode circuit. The grid supply voltage is set to the required value, and the grid pulse ignites the tube at the start of the current pulse period. The anode voltage waveform across the tube is then displayed on an oscilloscope using a capacitive potential divider if necessary. This anode waveform contains a small pulse during the conduction period. This pulse represents the tube voltage drop plus the small voltage drop in the current measuring resistor.

4.8.2.5 The trailing edge of this pulse serves as a reference and all the measurements are made from it. The amplitude of the anode probe pulse is set to the required value, having first set the time delay to near maximum. The oscilloscope shows the anode probe pulse in full when its leading edge is delayed from the cessation of conduction by a period greater than the recovery time of the tube to be measured. The forward anode probe pulse may then be advanced towards the current pulse until the anode pulse is clipped because forward re-ignition is occurring. The recovery time is taken as the minimum time after the cessation of conduction at which no clipping of the forward anode probe pulse can be seen.

PRECAUTION — The actual grid voltage when the probe pulse is applied may differ from the grid supply voltage. This is due to a grid ion current flowing through the resistor R_g and due to coupling of the grid to the anode probe pulse by the anode-grid capacitance. If it is not possible to measure the actual grid potential when the probe pulse is applied, the error produced by these effects should be kept to a minimum by using a low value of R_g.

When the recovery time is measured using pulse techniques, the rate-of-rise of the forward anode potential pulse must be greater than the rate of recovery of the critical anode voltage.

4.8.3 *Inverter Method* — The time necessary for recovery may be measured by connecting two of the tubes in an inverter circuit, as shown in Fig. 13.

4.8.3.1 It is common practice to use a tube of known characteristics in this circuit, together with the tube to be measured. The measurement circuit is similar to a full-wave single-phase rectifier except that the load, a dc generator in this case, can cause current to flow through the tubes.

4.8.3.2 Triggering pulses are applied to the grids of the tubes so that each tube ignites a short time before the alternating voltage on its anode becomes negative. The dc generator in combination with the smoothing reactor forces current through the tubes in opposition to the transformer voltage.

4.8.3.3 Thus, during the greater part of the ac cycle, power flows from the generator to the ac source. The operation of the circuit may be visualized by referring to the circuit of Fig. 13 and to the voltage and current waveforms in Fig. 14. Current to be flowing in tube No. 2, is assumed as shown in Fig. 14c. Since the voltage drop in the tube is small relative to the applied voltages, the voltage of point F in Fig. 13 may be assumed to be equal to that at point E as long as tube No. 2 is conducting. From Fig. 13 and 14a, it can be seen that, with tube No. 2 conducting, the anode of tube No. 1 is positive with respect to its cathode during the latter portion of the conduction cycle of tube No. 2 and tube No. 1 is kept from conducting only because its grid bias is more negative than the critical value. At point 2 of Fig. 14a, the grid of the tube No. 1 is pulsed as shown in Fig. 14j.

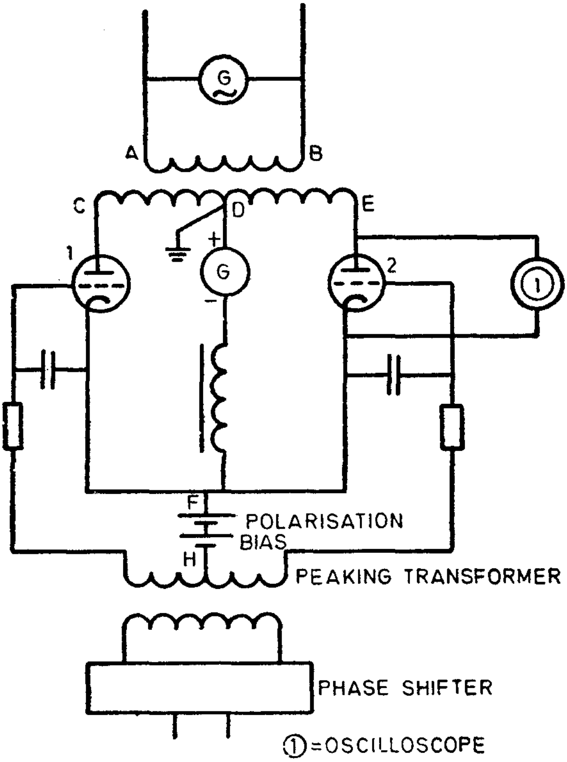


FIG. 13 INVERTER CIRCUIT FOR MEASURING RECOVERY TIME

4.8.3.4 Tube No. 1 immediately starts to conduct. However, because of the leakage inductance of the transformer, the current through the transformer secondary *DE* cannot stop instantly, and similarly the current through tube No. 1 and the transformer winding *CD* cannot build up instantly. Therefore, for a finite period, known as the commutation time, both tubes are conducting. Since point *C* of Fig. 13 is now positive and point *E* is negative, tube No. 1 continues to conduct and tube No. 2 ceases to conduct. The voltage from *F* to *D* across the inductance and the generator is as shown in Fig. 14e. It is the sum of the rectified alternating voltage and the direct voltage.

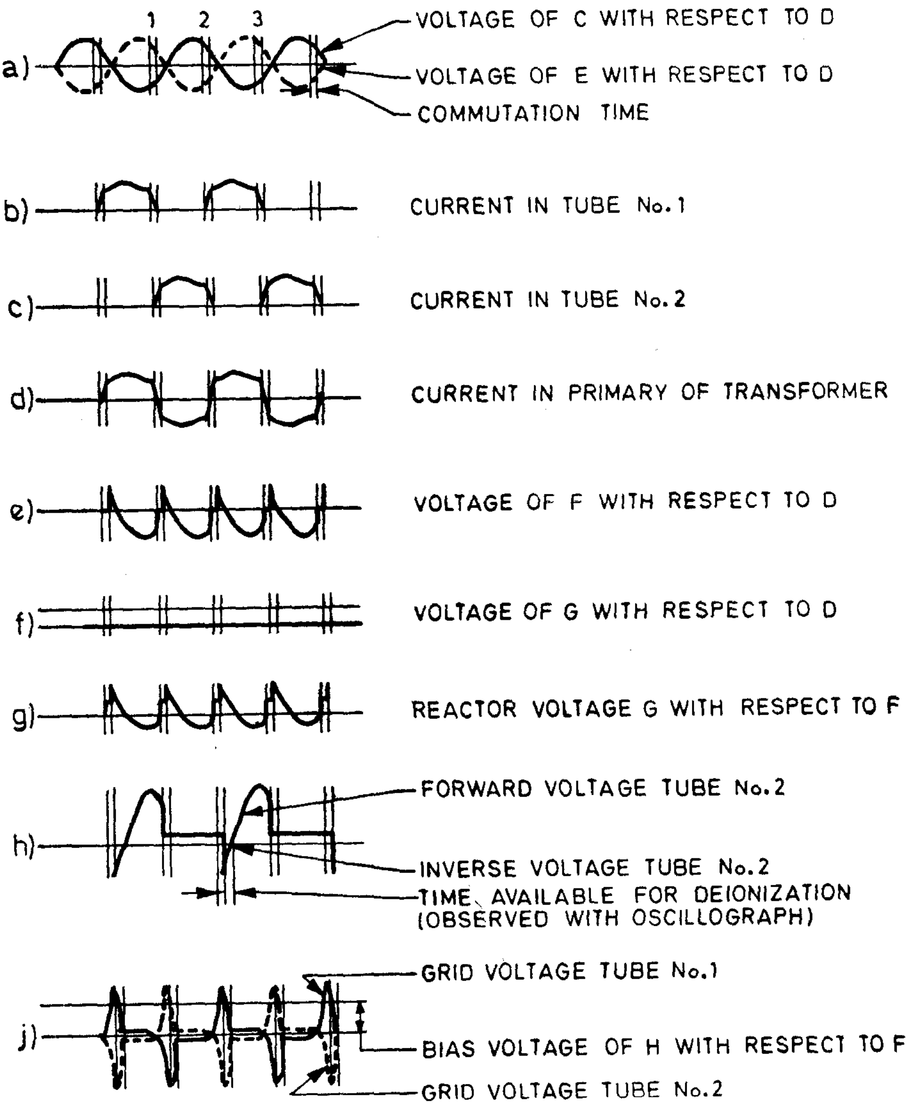

1
2
3
a)
VOLTAGE OF C WITH RESPECT TO D
VOLTAGE OF E WITH RESPECT TO D
COMMUTATION TIME
b)
CURRENT IN TUBE No. 1
c)
CURRENT IN TUBE No. 2
d)
CURRENT IN PRIMARY OF TRANSFORMER
e)
VOLTAGE OF F WITH RESPECT TO D
f)
VOLTAGE OF G WITH RESPECT TO D
g)
REACTOR VOLTAGE G WITH RESPECT TO F
h)
FORWARD VOLTAGE TUBE No. 2
INVERSE VOLTAGE TUBE No. 2
TIME AVAILABLE FOR DEIONIZATION (OBSERVED WITH OSCILLOGRAPH)
j)
GRID VOLTAGE TUBE No. 1
BIAS VOLTAGE OF H WITH RESPECT TO F
GRID VOLTAGE TUBE No. 2

FIG. 14 TYPICAL WAVEFORMS APPEARING IN THE INVERTER CIRCUIT FOR MEASURING RECOVERY TIME

4.8.3.5 The voltage of the anode with respect to the cathode of tube No. 2, shown in Fig. 14h is then the voltage of *E* with respect to *D* minus the voltage of *F* with respect to *D*. The method of adjustment of this circuit is as follows:

a) The dc bias is set at the value stated for the measurement.

b) With the dc generator disconnected from the inverter, the dc generator voltage is set to a low value compared with its operating value.

c) The alternating voltage is adjusted until the stated forward peak voltage is obtained.

d) The phase shifter is adjusted to ignite the tubes somewhat in advance of the desired phase.

e) Generators are connected to the circuit and the alternating voltage is raised until the tubes start to conduct an appreciable current.

f) The dc generator voltage and phase of ignition together are adjusted to obtain the desired average tube current. (Ignition later in the cycle or raising the anode current will change the inverse voltage and require adjustment of the generator voltage.)

g) The procedure is continued for the stated time and failures noted to commutate.

h) The measurement is repeated for longer or shorter times of negative anode voltage until a duration of negative anode voltage is established for the stated number of recovery failures per unit time.

4.8.3.6 The inverse and forward voltages on the tubes depend on the alternating voltage. The average amount of current flowing is a function of the direct voltage and of the angle of lag of the grid voltage at a given alternating anode voltage. When a tube re-ingites within the available time, the direct current rises to a high value. A circuit-breaker must therefore be provided in the dc circuit to protect the tubes. A choke should be used to smooth the current in case of re-ignition and to decrease the rate-of-rise of direct current on recovery failure, and thus to prevent the direct current from increasing sufficiently to damage the tubes within the operating time of the circuit-breaker. Commutation failure may result from failure of arc initiation in one of the tubes. The triggering grid voltage should therefore be made sufficiently positive for an adequate time to ensure reliable initiation of the arc.

4.9 Thyratron Ionization Time

4.9.1 With the filament or heater voltage at the desired value and the tube temperature adjusted to a value within the desired range, a voltage, either direct or alternating, is applied to the anode through a resistance of specific value. With the grid biased to a voltage substantially more negative (or less positive) than the critical grid voltage, an essentially rectangular voltage pulse of variable duration is applied in the grid circuit. The pulse should be of such value that the resultant grid voltage is less negative (or more positive) than the critical grid voltage by a specified amount and, when alternating anode voltage is used, should occur at the peak of the anode voltage wave. Conduction should take place within the time of the pulse duration, as indicated by a cathode-ray oscillograph. The minimum pulse duration when conduction takes place is the measurement result.

PRECAUTION — The time of rise of the applied pulse should be short compared with the ionization time to be measured.